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1. Your reference S12CISR2

2. Patent application number *(The Patent Office will fill this part in)* 0329289.3 17 DEC 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* Dr DAN MERRITT

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   Patents ADP number *(if you know it)* 5523360002

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

   INTERNAL COMBUSTION ENGINE

5. Name of your agent *(if you have one)* DW & SW GEE

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* APPLICANT'S ~~ADDRESS~~ 1 SOUTH LYON GDNS LONDON ROAD SHIPSTON ON STOUR CV36 4ER

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Signature(s) D. Merritt — D. Merritt — Date 16.12.2003

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom

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DUPLICATE

INTERNAL COMBUSTION ENGINE

This invention is an improvement to patent application number (GB) 0328471.8 filed on 9th December 2003. This invention relates to spark ignited reciprocating internal combustion engines.

Spark ignited engines rarely use indirect combustion chambers, preferring to burn the air fuel mixture directly above the piston. In contrast some compression-ignition engines have used indirect combustion chambers to advantage. Compression-ignition engines use high-pressure fuel injection capable of delivering fuel directly into the combustion chamber at the end of the compression stroke. Systems capable of injecting gasoline fuel directly into the combustion chambers of spark-ignited engines have recently been used in gasoline direct injection or GDI engines. Most GDI engines use direct combustion chambers situated immediately above the piston.

This invention seeks to provide a spark ignition engine, with improved thermal efficiency, by operating with an indirect combustion chamber of a novel design. Accordingly this invention provides an internal combustion engine comprising:

a piston reciprocating in a cylinder;

air inlet means communicating with the cylinder;

exhaust means communicating with the cylinder;

an indirect combustion chamber communicating with the cylinder;

transfer orifice means communicating with the cylinder and the combustion chamber;

spark ignition means communicating with the combustion chamber;

fuel injection means communicating with the combustion chamber;

management means to control the fuel injection process and spark ignition event;

characterised in that the fuel injection means and the transfer orifice means are adapted to enable the said fuel injection means to deliver fuel into the cylinder through the said transfer orifice means during the induction stroke of the piston and in that the said transfer orifice means is adapted to promote and direct a jet of gas to flow into the combustion chamber during the compression stroke of the piston the said jet having capability to entrain and vaporise fuel injected into the jet by the said fuel injection means during the compression stroke of the piston and to convey said vaporised fuel within the said combustion chamber to be ignited by the spark ignition means.

The term air is used herein to describe air which is either pure or contains other gases such as products of combustion or even hydrocarbon gases. The term mixture describes air mixed with vaporised fuel destined for combustion. The term gas is used to describe either air or mixture.

The term clearance volume is used herein to describe a volume situated immediately above the piston when at the end of the compression stroke. It may contain mixture.

The term combustion chamber is used herein to describe a volume separated from the clearance volume by the transfer orifice means in which combustion is always initiated by the spark ignition means. It contains apertures providing access to the fuel injection means and the spark ignition means.

The combined volumes of the combustion chamber and clearance volume determine the geometrical compression ratio chosen for the engine. For a given compression ratio maximising the combustion chamber's volume will minimise the clearance volume and vice versa.

The geometry of the combustion chamber and the positioning of the transfer orifice mean aperture will dictate the type of gas motion within the chamber, following the transfer of gas from the cylinder into the chamber during the compression stroke. Gas

motions may be chosen to promote either stratification or mixing between the air and fuel within the combustion chamber according to the wishes of the engine designer.

The term stratification is used herein to describe gas movements which promote a non homogeneous blending of fuel and air within the chamber so that a spark ignitable mixture ends up near the spark ignition means when the piston reaches the end of the compression stroke and air or gas which is not spark ignitable ends up elsewhere within the combustion chamber.

The term lean mixture is used herein to describe gas that is not ignitable by the spark ignition means used in the engine.

The term lean burn capability is used herein to describe the ability of an engine to perform with an overall air/fuel mixture that is a lean mixture, by using stratification.

The term helical swirl used herein describes gas movement in the combustion chamber wherein the gas rotates around the periphery with an axial inclination away from the transfer orifice means in screw thread fashion. It is further described in the text explaining Fig. 3.

The term toroidal circulation is used herein to describe gas movement in the combustion chamber wherein the gas rotates along axial directions describing a toroidal envelope, its outer surface moving axially along the periphery and its inner or core surface moving axially, in the opposite direction, along the jet of gas emerging from the transfer orifice means. It is further described in the text explaining Fig. 6.

During the compression stroke the piston delivers gas into the combustion chamber through the transfer orifice means in a form of a jet. The gas may be air when no fuel is injected into the cylinder during the induction stroke or it may be mixture in the alternative. The velocity of the jet will vary from zero to maximum and back to zero during the compression stroke.

Preferably the fuel injection means points a fine spray of fuel directly into the jet of gas flow emerging from the transfer orifice means into the combustion chamber

during the compression stroke. Preferably the shape and spray droplet size are designed to allow as much fuel as possible to be captured, entrained and vaporised within the said gas jet.

Preferably the shape of the spray is a cone with an angle chosen to allow as much fuel as possible to pass cleanly through the transfer orifice means during the induction stroke. Wetting of the walls of the chamber and the orifice may be unavoidable but if moderate it should not impede the performance of the engine.

Preferably the size of the transfer orifice means is chosen to promote a jet of gas, during the compression stroke of the piston, with sufficient velocity to entrain as much fuel as possible and reverse its direction of movement.

Preferably, but not essentially, the axis of the fuel delivery means nozzle trajectory and the axis of the transfer orifice means are substantially coincidental.

Preferably the management means provides control of the timing and quantity of fuel delivery by controlling both the duration of injection and where necessary the pressure of fuel supply to the fuel injection means.

Some of the advantages of engines constructed according to this invention are listed below:
Volatile fuel injected into a jet of air or mixture delivered to the combustion chamber by the piston during the compression stroke can undergo rapid vaporisation.

The transfer orifice means size and orientation allows engine designers to select various gas movements within the combustion chamber with relative ease. This can achieve either stratification or alternatively effective mixing of fuel and air over a wide range of engine conditions.

The ability of the fuel injection means to deliver fuel into the cylinder as well as the combustion chamber can be of benefit in a number of ways which may also depend on the volume chosen for the clearance volume. One benefit, for example, is where the clearance volume is minimised. For high fuelling conditions and /or high engine

speeds, fuel may be injected continuously during the induction stroke and during the compression stroke. This allows some of the fuel to vaporise in the cylinder and some in the combustion chamber and extends the time period available for vaporisation.

Another benefit is for an engine designed with a substantial clearance volume. In this case the combustion chamber can be designed to meet the engine's load requirements from idling to say mid range, by using stratified charge gas movements in the combustion chamber, so avoiding the need to throttle the air intake to the cylinder over this load range. The clearance volume will only be provided with fuel when operating above this load range when the combustion chamber, which operates with a spark ignitable mixture, is capable to ignite lean mixtures within the clearance volume. In this way an engine according to this invention may minimise or even dispense with the need to throttle the air intake into the cylinder to meet part load conditions.

An engine according to this invention can operate with higher thermal efficiency compared with other spark-ignited engines. The combustion chamber is effectively cooled by vaporising fuel injected into it. Latent heat to vaporise the fuel is extracted from the walls during the compression stroke. This reduces the need for external coolants that contribute to a loss of thermal efficiency. This advantage also reduces the risk of pre-ignition and allows higher compression pressures to be used.

If the combustion chamber's volume is maximised, and no fuel is injected into the cylinder, hydrocarbon emissions from fuel trapped in piston crevices can be eliminated.

The combustion chamber's compact volume promotes a rapid combustion process ensuring a constant volume engine cycle that provides the highest theoretical thermal efficiency.

The avoidance of throttling of intake air to meet part load conditions also increases the engine's thermal efficiency.

This invention is further described hereinafter by the way of example, with reference to the accompanying schematic drawings which are not to scale and are presented for illustration purposes only;

Figure 1 is a sectional elevation of one embodiment of an internal combustion engine according to this invention.

Figure 2 is a sectional elevation of a similar embodiment showing fuel injection into the cylinder during the induction stroke.

Figure 3 is similar to Fig. 2 showing fuel injection during the compression stroke in a combustion chamber designed to stratify the mixture to enable lean burn in the chamber.

Figure 4 illustrates a section through a cylindrical combustion chamber, designed to stratify, which is inclined to the axis of the engine's cylinder showing details of access geometry for the fuel injector means and transfer orifice means.

Figure 5 illustrates a sectional view of a similar combustion chamber shown in Fig. 4 along line A-A.

Figure 6 illustrates a sectional view of a symmetrical chamber based on a truncated sphere designed to promote homogeneous mixing in toroidal manner, and also illustrates fuel injection during the compression stroke and a piston with a cavity on its crown designed to provide clearance volume.

Referring to the drawings by way of examples, Figure 1 shows piston 1, cylinder 2 moving along axis 18, air inlet means in the form of an inlet valve 3, exhaust means as valve 4, flame plate 5 and an indirect combustion chamber 6.

The combustion chamber 6 provides access for the fuel injection means, a fuel injector 11 and the spark ignition means, a spark plug 9, situated at the optimum location for reliable ignition. The combustion chamber communicates with cylinder 2 through transfer orifice means 7 situated at the near end of the combustion chamber

marked 8. In this illustration the axis of the chamber 19 is parallel with the axis of the cylinder 18 and the axis 20 of the transfer orifice means 11, is shown coincident with the axis 20 of the transfer orifice means 7.

The management means 12, determines the quantity of fuel flowing through the fuel line 13, the timing of fuel injection and the spark event amongst other parameters.

In Figure 1 the transfer orifice means 7 and fuel injection means 11 are shown as dotted lines where situated behind the cross sectional view. This is one particular design feature, which promotes stratification in the chamber. It induces the jet of gas emerging from the transfer orifice means during the compression stroke to proceed to move in helical swirl flow in the combustion chamber as explained later. The geometry is also illustrated in Fig. 4 and Fig. 5. For the sake of simplicity Fig. 2 and Fig. 3 omit to show such dotted lines although they also illustrates a similar stratifying chamber. Fig.1 to Fig. 5 all illustrate different features of this invention and for simplicity use stratifying chambers of a similar design. This is not intended to suggest that such particular design is essential. Other chamber shapes designed to promote other gas motions are also possible and one is illustrated in Fig. 6 to represent one example of alternative chambers designed to promote a homogeneous mixtures.

The axis 20 of the fuel injection means 11 is shown coincident with the axis of the transfer orifice means 7 and Figure 2 illustrates how this facility is used to allow fuel spray to be injected into the cylinder 2. This is possible during the induction stroke of piston 1 illustrated by arrow D, because at that time there is no gas entering the combustion chamber from the cylinder. The two axes need not be coincidental but the positioning of the fuel injection means must allow some fuel to enter the cylinder during the injection period. The size of the transfer orifice means 7 and the conical spray 17 shown need to be matched to ensure entry of a sufficient fuel quantity.

Figure 3 illustrates the combustion chamber illustrated in Fig. 2 when the fuel injection spray 17 is impinging on the jet of gas emerging from the transfer orifice means during the compression stroke of piston 1 illustrated by arrow D. The gas will be air if no fuel was previously injected into the cylinder but will be a mixture of fuel and air if it had been. The velocity of the jet ensures that fuel is entrained by the jet

and transported in the opposite direction into the combustion chamber. The intense interaction promotes rapid vaporisation of the liquid fuel spray that in turn cools the gas by extracting latent heat from it. In turn the cooled gas will assist in removing heat from the combustion chamber's walls.

Figures 2 and 3 between them illustrate the capability of indirect combustion chambers constructed according to this invention to perform the following tasks;

a) To deliver to the combustion chamber a spark ignitable mixture, using a jet of air that rapidly vaporises volatile liquid fuel and delivers it towards the spark ignition means 9.

b) To allow fuel to be injected into the cylinder when necessary, to be vaporised therein and subsequently to be delivered into the combustion chamber during the compression stroke. This facility may be used when extra time is needed to ensure effective vaporisation of the fuel, for example at high loads, when fuel delivery is maximised, or at high engine speed when time available for the injection process is reduced.

The gas movement within the combustion chamber may be designed either to stratify the spark ignitable mixture from unignitable gas, or to generate a mixing motion aimed at achieving a homogeneous spark ignitable mixture within the combustion chamber.

Figure 3 is also used to illustrate one method of stratifying gas movement within the combustion chamber which allows engines constructed according to this invention to operate with lean mixtures overall so as to minimise or even eliminate the need to throttle the air intake to the engine.

It has been observed, in an experiment, that helical swirl flow can be easily produced by directing a jet of compressed air delivered from a nozzle, onto the internal wall of a vertical glass cylinder closed at its upper end. The nozzle is positioned at the lower, open end, against the inside of the glass wall at an angle to the axis of the cylinder to give a tangential velocity component around the periphery, for example forty-five degrees. Fine powder made of solid particles, for example talcum powder, is placed

inside the glass cylinder before it is inverted, and if the inversion takes place after the air flow had started the fine powder does not fall down but remains rotating around the periphery at the top of the cylinder, as a ring, for as long as the air jet induced helical swirl flow is maintained. When the airflow is stopped the powder motion also stops and it drops downwards by gravity falling out of the cylinder. This phenomenon is applied to air containing fuel vapour and possibly some fine fuel droplets, in the recognition of its ability to stratify spark ignitable mixture formed within the jet and to confine it in rotation at the location of a spark plug.

Figure 3 illustrates air motion in the combustion chamber during the compression stroke by way of an imaginary stream tube. The gas in cylinder 2 is forced into the combustion chamber 6 through the transfer orifice means 7 whose axis 20 is offset from the axis 19 of the combustion chamber and is inclined to it in a direction, which has a tangential component to the periphery 22 of the combustion chamber but is not shown in this diagram. This creates a jet of gas, which meets the cylindrical wall of the combustion chamber at an oblique angle with tangential and axial velocity components, causing it to deflect tangentially and flow around the cylindrical wall of the combustion chamber and in a forward direction, like a screw thread, a motion termed helical swirl. When a stream tube reaches the far end 10 of the chamber it loses its axial velocity component. This causes a pressure rise downstream which decelerates the gas following. The gas reaching the far end 10 continues to swirl around the chamber wall and is pressed against the far end as shown in zone 15. Gas that follows keeps pressing the swirling mass that entered earlier against the far end and adjacent to the spark plug 9. Stream tubes generated when the jet's velocity is highest, after the piston reaches its highest velocity during the compression stroke, will possess greater momentum and may penetrate or displace the earlier stream tubes, which were generated when the gas jet had lower velocities. The high momentum stream tubes, which finally settle near the spark plug, should contain fuel in a spark ignitable mixture because they are likely to become stratified and remain in position near the spark plug even after fuel delivery stops for later air stream tubes. These stratified stream tubes containing a mixture will burn even if the gas upstream is air without fuel.

If fuel injection into the cylinder is to be avoided, the timing of fuel injection is chosen to take place after the commencement of the compression stroke when suitable momentum is established in the gas jet emerging from the transfer means orifice 7, in order to ensure good entrainment of fuel spray into the gas.

Figure 4 illustrates a generalised embodiment of a cylindrical combustion chamber designed to produce stratifying gas movement but with its axis 19 set at an angle to the axis 18 of cylinder 2. This orientation can offer advantages; it can reduce engine height, improve access to spark plug 9 and fuel injector 11 and it can allow less acute helix angles between axes 19 and 20 if needed, when promoting helical swirl flow in the combustion chamber. For example, if the angle between the axis 20 of the transfer orifice means 7 and the axis 18 of cylinder 12 in the plane shown is made ninety degrees, the aperture of the transfer orifice means 7 on the flame plate 5 at the top of cylinder 2 will be circular so minimising the area on the flame plate used for the orifice. Figure 4 is a section along line B-B taken through and along the axis of symmetry 19 of the combustion chamber, and does not contain the axis 18 of the cylinder. The transfer orifice means 7 can be seen entering the combustion chamber in the vicinity of the near end 8 in a direction pointing a jet of air to rotate around the periphery of the cylindrical combustion chamber 22 in helical swirl flow towards the far end 10. The fuel injection means 11 is shown pointing its spray (not shown) directly at the transfer orifice means and its axis is the same as axis 20. Preferably the cone angle of the fuel spray is chosen to match the circular cross section of the transfer orifice means as it enters the combustion chamber, in other words the cross section of the air jet emerging from it, so as to ensure maximum entrainment of fuel into the jet of air.

Figure 5 illustrates a cross-section along line A-A shown in Figure 4 of a similar combustion chamber to that illustrated in Figure 4. No attempt was made to match the angle of entry of the transfer orifice means 7 into the cylinder through the flame plate 5, in both the diagrams. The section is taken across the longitudinal axis of symmetry of the combustion chamber to show the relative orientation of the transfer orifice means 7 and the fuel injection means 11 consistent with the promotion of helical swirl flow, a feature that was not illustrated in the schematic diagrams of Figures 2 and Figure 3.

The tangential entry of the transfer orifice means 7 relative to the circumference 22 is clearly shown in this diagram as well as the proximity of the fuel spray (not shown) emitted by fuel injection means 11 to the exit of the transfer orifice 7. The fuel injection means is shown in a cavity 110, which protects it from contact with the flame.

An alternative gas movement possible within the combustion chamber is a mixing motion. This can be done in a number of ways. One such motion is illustrated in Figure 6. One of the basic requirements, according to this invention, that the fuel injection means is capable to deliver fuel into the cylinder 2 through the transfer orifice means 7 is preserved in this design. However, in this example, the orifice is placed along the axis of symmetry of the chamber, which is spherical with a truncated far end. The spark ignition means 9 is placed at the location which provides best ignition performance. The far end of the chamber is the end furthest from the transfer orifice means and vice versa.

The gas jet entering the chamber during the compression stroke is designed to be capable to entrain the spray of fuel 17 injected into it and convey it in the opposite direction into the chamber, this being a second basic requirement according to this invention. On reaching the far end of the chamber the gas jet deflects radially outwards and then follows the contour of the chamber towards the nears end. On reaching the near end of the chamber the gas changes it direction again and moves along the periphery of the jet towards the far end. The gas movement forms a toroidal shape. If the far end contains spiralling groves cut into the metal a spinning motion may be added to the toroidal movement enhancing mixing action.

Figure 6 also illustrates a piston whose crown contains a cavity 100, which provides clearance volume. It may contain a quantity of mixture, lean or stoichiometric, at the end of the compression stroke to be ignited by the flame emerging from the transfer orifice means 7 during the combustion period. Such clearance volume is not essential but engines according to this invention can be designed to use it with advantage.

An engine according to this invention can operate in a number of fuel delivery modes depending on the choice of the designer. The modes are met by programming the management means of the engine accordingly. The choice may be influenced by, amongst others, the choice of fuel, the speed range, the choice of clearance volume and the swept volume capacity. An engine may use more than one mode over its range of operations or an engine may be designed to operate exclusively in one of the modes over its full range of operations.

Mode-1: Most of the fuel is injected into the air during the compression stroke period.
Mode-2: Most of the fuel is delivered into the cylinder, through the transfer orifice means, during the induction stroke period.
Mode –3: A combination of mode 1 and mode-2 where some of the fuel is involved in each of the modes rather than most of the fuel. A single fuel delivery event per engine cycle may be sufficient starting during the induction stroke and continuing into the compression stroke period.

To operate in modes-2 and mode-3 the fuel injection means nozzle needs to be aligned with the transfer orifice means so as to allow the maximum amount of the injected fuel to enter the cylinder through the said orifice means during the induction stroke of the engine. To operate in mode 1 the fuel injection means needs only to be able to deliver fuel into the jet of air emerging from the transfer orifice means during the compression stroke.

In designs where the clearance volume is not minimised, an engine according to this invention is preferably operated in mode-1 at idling and low to medium loads and mode 3 at higher loads and the gas movement in the combustion chamber should be designed to stratify. Such designs may remove the need to throttle the air intake to the engine altogether.

In designs where the clearance volume is minimised an engine according to this invention can operate only in mode-1 from low loads to medium high loads and only in mode-2 to meet higher load conditions up to maximum load conditions at high engine speeds. In this case a stoichiometric or near stoichiometric amount of fuel can be delivered into the cylinder during the induction stroke and subsequently transferred

into the combustion chamber during the compression stroke where it will form a spark ignitable mixture to be ignited by the spark ignition means. This mode allows maximum time for the fuel to vaporise, a useful capability when operating at such conditions.

Alternatively an engine with minimum clearance volume can operate at high loads in mode-3, ensuring a spark ignitable mixture at the spark ignition means by using some fuel in mode-1 to top up the fuel quantity in the mixture that was achieved in mode-2. Preferably such an engine uses a stratifying gas motion in the combustion chamber to ensure reliable ignition at part loads.

An engine according to this invention designed to operate in mode-1 or mode-3 with minimum clearance volume may need some degree of throttling of the inlet air over a limited load range for example when idling or when operating at low load conditions. Under such conditions it may be impossible to form a spark ignitable mixture using mode-1 even within the stratified charge zone reaching the spark ignition means. Reducing the mass of air flowing through the transfer orifice means during the compression stroke, for a given mass of fuel injected, can restore the mixture to become spark ignitable whilst the overall air /fuel ratio of the mixture remains lean and not ignitable by a spark. The amount of throttling required is much reduced in comparison with other engines that operate with homogeneous stoichiometric mixtures over the full range of operations.

An engine according to this invention, with a stratified charge combustion chamber, can be constructed to dispense with the need to throttle the air intake to meet the conditions mentioned above. This is achievable by providing a clearance volume that is greater than the minimum clearance volume that is possible to achieve. The clearance volume is the volume within the cylinder above the piston when the piston is at the end of its compression stroke. In such an engine the clearance volume will contain some of the air needed for combustion and the volume of the combustion chamber will be reduced to compensate for this so as to yield the desired compression ratio. Such an engine can operate in mode-1 at low part loads and when idling and avoid the need to throttle the inlet air under these conditions since the mixture within the combustion chamber will be richer at the end of the compression stroke compared

with another engine with a smaller clearance volume. To meet greater loads such an engine will change the mode of operation to mode-3

If an engine operating in mode-3, is constructed according to this invention with a clearance volume that is substantially greater than the combustion chamber's volume, the combustion chamber can be regarded as an ignition amplifier capable of transforming a low energy spark into a flame torch of high energy capable of igniting lean mixtures in the clearance volume.

The sequence of operations is described by way of an example based on perception for an engine constructed according to this invention, using a stratified charge combustion chamber, when operating in fuel delivery mode-1. Some operational features of such an engine may change with rotational speed and load, in particular the timing and duration of fuel injection. The operation is therefore described at a given engine speed and load and in a four-stroke embodiment as illustrated in Figure 1. The engine performs an exhaust stroke followed by an induction stroke in the usual manner. After the commencement of the compression stroke air is transferred from cylinder 2 into combustion chamber 6 through transfer orifice means 7. When such airflow is established as a jet sufficiently strong to entrain a spray of gasoline aimed directly at it in the opposite direction, the management means 12 energises the fuel injector 11 to spray into the air jet a cone of finely atomised mist. The cone angle is chosen so as to produce a circular cross section of approximately the diameter of the air jet emerging from the transfer orifice which is this example is chosen to be circular in cross section. This helps to ensure that most if not all the fuel is entrained within the air jet. Fuel injection ceases when the required quantity is delivered to meet the desired load condition, but it is set to be discontinued automatically by the management means 12 towards the end of the compression stroke of piston 1 when the air jet entering the combustion chamber is greatly weakened. At higher engine speeds the quantity of fuel injected per unit of time may need to be increased by increasing the pressure of the fuel delivered to the fuel injector or by enlarging the fuel injector's delivery flow area.

The fuel entrained in the air jet is at least partially vaporised and the mixture continues to swirl around the walls of the combustion chamber in helical swirl

motion, like a screw thread, moving towards the far end of the combustion chamber. Vaporisation continues when heat is absorbed from the cylindrical walls of the combustion chamber, which had been heated up during the combustion period of the previous cycle. In this way the combustion chamber's wall is cooled cycle after cycle so minimising the need to use external coolant. The compressed mixture also undergoes a reduction of its temperature towards the end of the compression stroke, as a result of vaporisation, and pre ignition dangers are reduced. If turbo-charging is used the need to lower the compression ratio of the engine in order to avoid pre-ignition is also reduced.

After fuel injection ceases further air entering the combustion chamber 6 from cylinder 2 will also be imparted helical swirl motion and compress the mixture that entered earlier. The mixture rotates pressed against the far end 10 of the combustion chamber. There may be some fuel diffusion and mixing in the boundary between the mixture and the air following it but this will not destroy the stratification needed to ensure reliable spark ignition of the fuel in the mixture rotating near the spark plug. The combustion process can be completed within the combustion chamber and the hot gases will move into cylinder 2 through orifice 7 to transfer energy to piston 1 in the usual way.

It is perceived that a quantity of fuel delivered to the air jet when it is at its maximum velocity, well after the compression stroke started, will be carried towards the far end 10 of the combustion chamber and reach the spark plug, penetrating through the swirling air or mixture which entered beforehand, due to its higher momentum. If this is found not to be so the spark plug may be situated on the periphery at a distance from the far end 10 of the combustion chamber, so as to be in contact with the ignitable mixture zone.

The fuel injection process must be correctly timed. It is envisaged that combustion is completed rapidly and within the combustion chamber due to the swirling movement of the mixture. In mode-1 fuel is excluded from the cylinder and therefore cannot be trapped in crevices near the piston rings and valves.

When operating at maximum load in mode-1 the maximum amount of fuel injected should be sufficient to form a stoichiometric mixture within the combustion chamber and the injection period extended as far as possible within the compression stroke period consistent with fuel retention within the chamber. When a vehicle driver uses the engine hereby described, increasing the duration of fuel injection in terms of crank angle degrees will increase the output torque. If the torque exceeds the resistance to motion the engine and vehicle speed will increase. The time available for fuel injection over the selected number of crankshaft degrees will be reduced. If needed to overcome this, fuel line pressure can be made to increase with engine speed in a predetermined proportion exercised by the management means 12.

The sequence of operations in mode-2 or mode-3 is described by way of an example based on the embodiment illustrated in Figure 1. After the commencement of the induction stroke fuel is injected directly into cylinder 2 through the transfer orifice means 7. As there is no jet of gas passing through at that time the fuel will enter into the cylinder, possibly reaching the crown of the hot piston where it vaporises and mixes with the air induced into the cylinder through inlet valve 3. In mode-2 operations the fuel delivery stops before the commencement of the compression stroke but in mode-3 fuel delivery will continue into the compression stroke. It is obvious that during the early part of the compression stroke fuel will continue to enter the cylinder since the jet of gas will have insufficient strength to entrain it. The mixture formed in the cylinder will be transferred into the combustion chamber 6 during the compression stroke and in mode-3 some extra fuel may be added to the jet of mixture discharged from the transfer orifice means 7 to assist in forming a spark ignitable mixture at the spark ignition means 9 at the far end 10 of the combustion chamber. If an engine constructed according to this invention is designed to have an enlarged clearance volume with a reduced combustion chamber volume, as described earlier, an appreciable quantity of mixture may remain in the cylinder above the piston at the end of the compression stroke. After ignition the flame in the combustion chamber together with the increased temperature and pressure will cause the mixture in the clearance volume above the piston also to ignite and burn.

The sequence of operations in mode-3 is described by way of an example for an engine according to this invention with a clearance volume and a non-stratifying combustion chamber similar to the example illustrated in Fig. 6.

After the commencement of the induction stroke fuel is injected into cylinder 2 at a suitable timing as explained in the previous example. The injection period continues into the compression stroke until the quantity of fuel delivered is sufficient to form a spark ignitable homogeneous mixture in the combustion chamber at the end of the compression stroke. This is ignited by the spark plug and the flame will cause a lean mixture in the clearance volume also to ignite and burn. A limited amount of throttling of intake air may be needed to adjust the quantity of air in the chamber or in the clearance volume to form ignitable mixtures with a given quantity of fuel.

This invention is suitable for use with the two-stroke engine cycle if it uses fuel delivery mode-1 only and if fuel injection starts only after the exhaust passage is closed. Such two-stroke engines can be either crankcase aspirated or externally aspirated. As no unburnt fuel enters the cylinder at any time the typical disadvantage of blowing fuel into the exhaust duct is removed. The crankcase and crevices around piston rings will also be free from trapped hydrocarbons. The combustion chamber will contain some products of combustion from the previous cycle, but this is considered beneficial for reducing the amount of Nitrogen Oxides in the exhaust gases.

CLAIMS

1. An internal combustion engine comprising;

a piston reciprocating in a cylinder;

air inlet means communicating with the cylinder;

exhaust means communicating with the cylinder;

an indirect combustion chamber communicating with the cylinder;

transfer orifice means communicating with the cylinder and the combustion chamber;

spark ignition means communicating with the combustion chamber;

fuel injection means communicating with the combustion chamber;

management means to control the fuel injection process and spark ignition event;

characterised in that the fuel injection means and the transfer orifice means are adapted to enable the said fuel injection means to deliver fuel into the cylinder through the said transfer orifice means during the induction stroke of the piston and in that the said transfer orifice means is adapted to promote and direct a jet of gas to flow into the combustion chamber during the compression stroke of the piston the said jet having capability to entrain and vaporise fuel injected into the jet by the said fuel injection means during the compression stroke of the piston and to convey said vaporised fuel within the said combustion chamber to be ignited by the spark ignition means.

2 An engine according to claim 1 wherein the said fuel injection means is situated to deliver fuel directly towards the said jet of gas along an axis coincident or parallel with the axis of the said jet.

3. An engine according to claims 1 and 2 wherein the said transfer orifice means is aligned with the axis of the delivery nozzle of the said fuel injection means to allow fuel to be injected into the said cylinder.

4. An engine according to any of the preceding claims wherein the nozzle of the said fuel injection means is situated within a cavity communicating with the said combustion chamber.

5. An engine according to any of the preceding claims wherein the clearance volume is minimised within mechanical constraints.

6. An engine according to claims 1 to 3 included wherein the said combustion chamber volume is reduced in order to enlarge the clearance volume.

7. An engine according to any of the preceding claims wherein the said management means activates fuel delivery only into the said combustion chamber during the compression stroke.

8. An engine according to any of the preceding claims excluding claim 7 wherein the said management means activates fuel delivery into both the said combustion chamber and the clearance volume.

9. An engine according to any of the preceding claims wherein the gas movement within the combustion chamber is designed to promote lean burn capability.

10. An engine according to any of the preceding claims wherein the gas movement within the combustion chamber is designed to promote helical swirl motion.

11. An engine according to any of the preceding claims, excluding claims 9 and 10, wherein the gas movement within the combustion chamber is designed to promote homogeneous mixtures.

12. An engine according to claim 11 wherein the gas movement within the combustion chamber is designed to promote toroidal circulation.

13. An engine according to any of the preceding claims wherein air induction into the cylinder is not restricted in order to operate at part load.

14. An engine according to any of the preceding claims operating on the four-stroke cycle.

15. An engine according to any of the preceding claims excluding claim 14 operating on the two-stroke cycle.

16. An engine according to any of the preceding claims wherein the said combustion chamber is situated with its longitudinal axis not parallel with the direction of the axis of the engine's said cylinder.

ABSTRACT

A spark ignition reciprocating engine with an indirect combustion chamber operating according to either four or two stroke cycles. Fuel is injected into the chamber either during the compression stroke, or the induction stroke or both. The fuel injector is aligned with the transfer port connecting the chamber with the cylinder so that fuel can be delivered directly into the cylinder through it during the induction stroke. During the compression stroke, the jet of compressed air or mixture delivered through the port by the piston entrains the spray of fuel, transports it into the combustion chamber towards the spark plug and rapidly vaporises it. Gas movement within the chamber is influenced by port geometry and can promote stratified charge giving lean burn capability in the chamber. The chamber may also be used to ignite lean mixtures in a clearance volume. Throttling at part load may be eliminated by suitable designs.

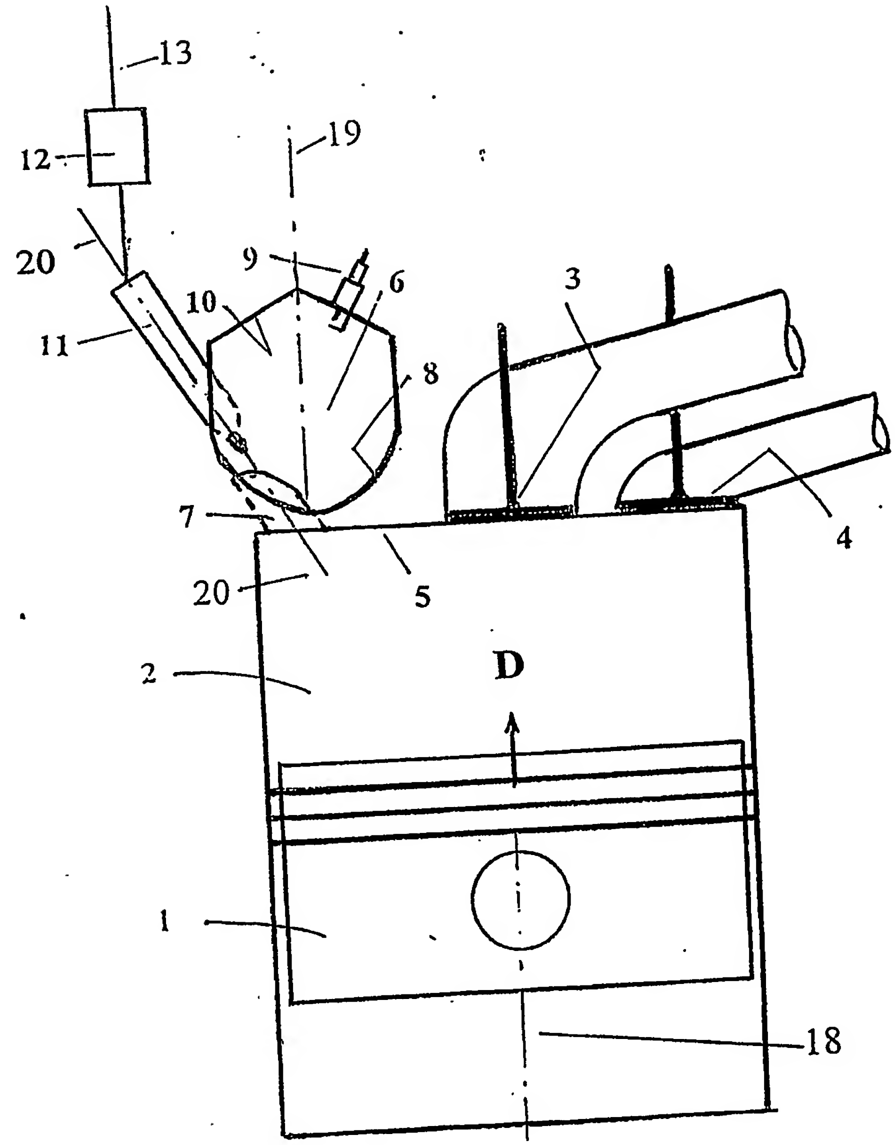


FIG 1

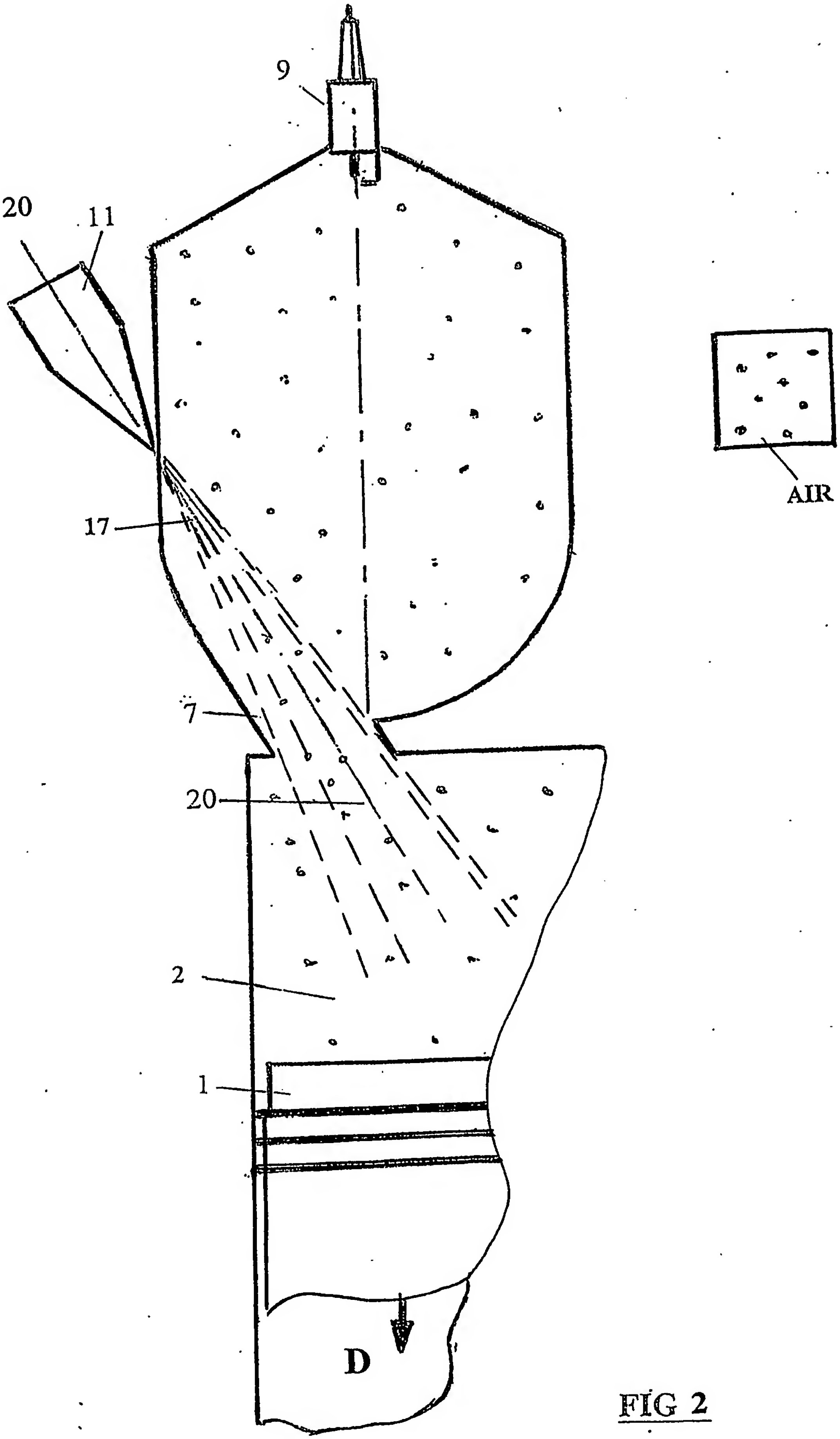


FIG 2

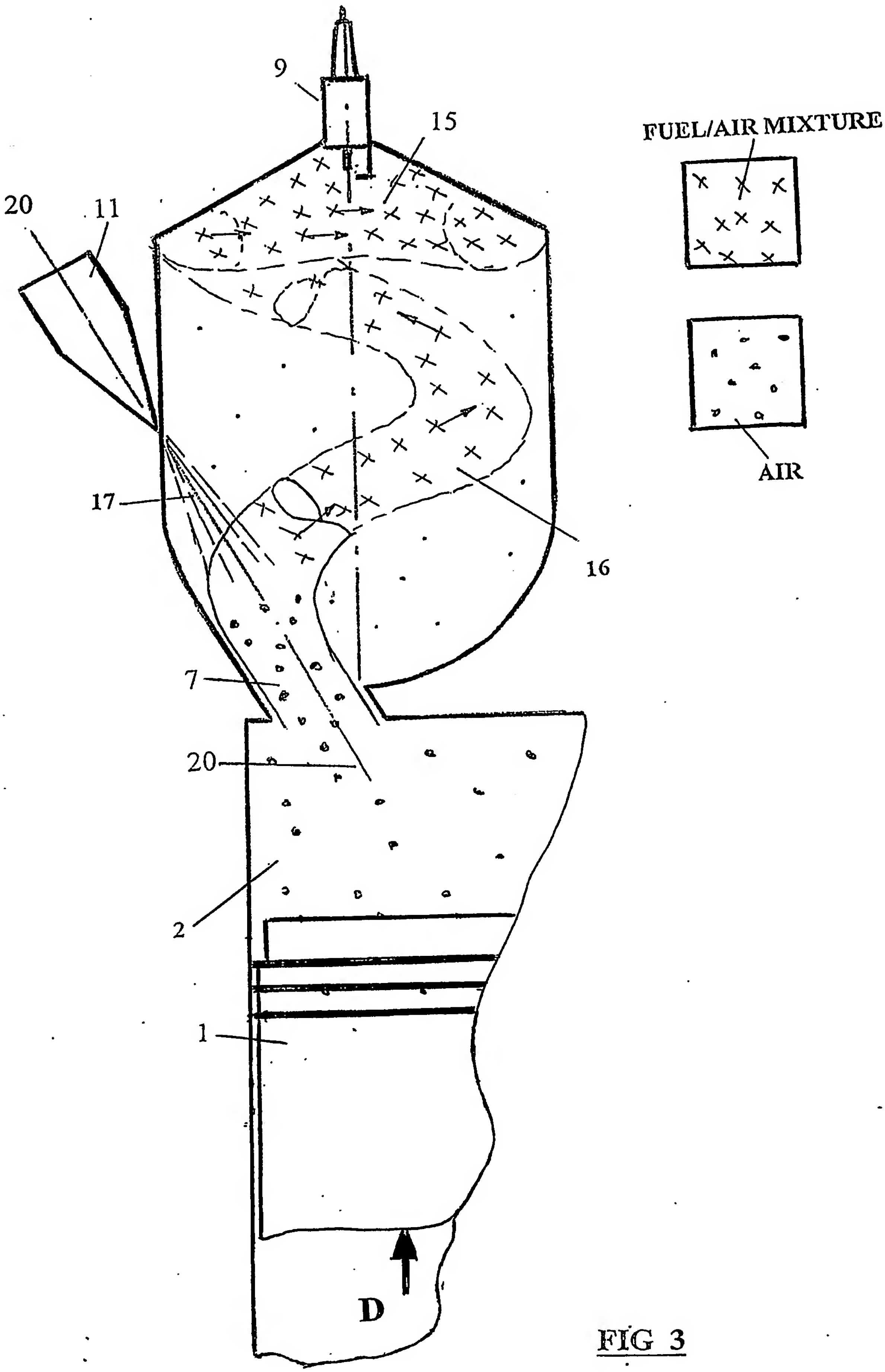
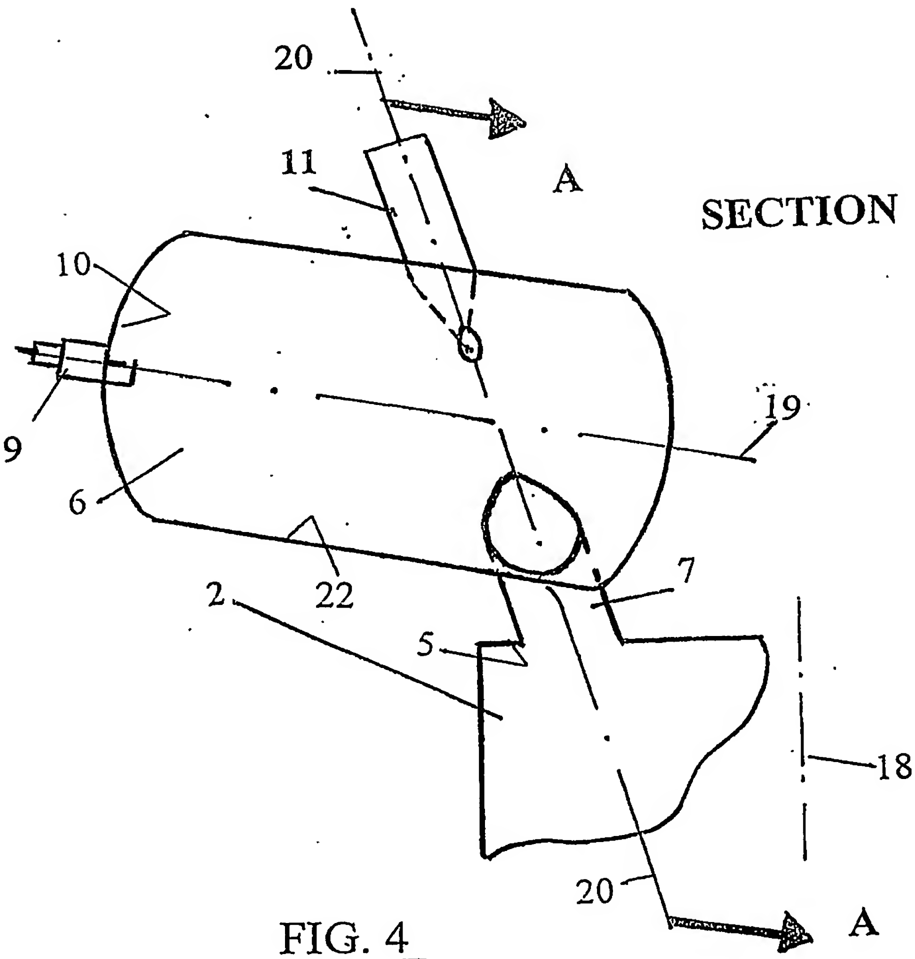


FIG 3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9
19
6
2
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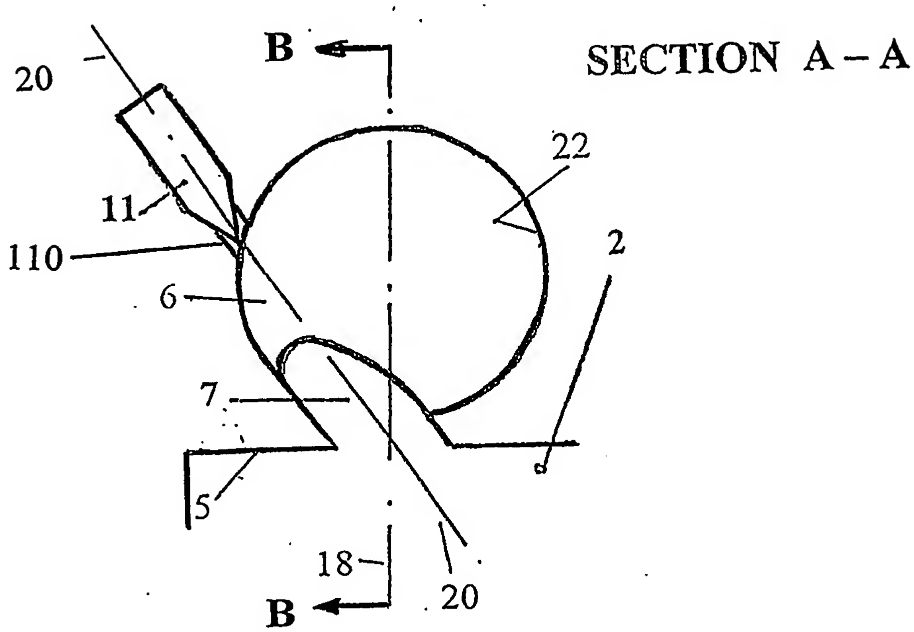
7
5
18
20
A

FIG. 4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7
5
18
20
B

FIG. 5

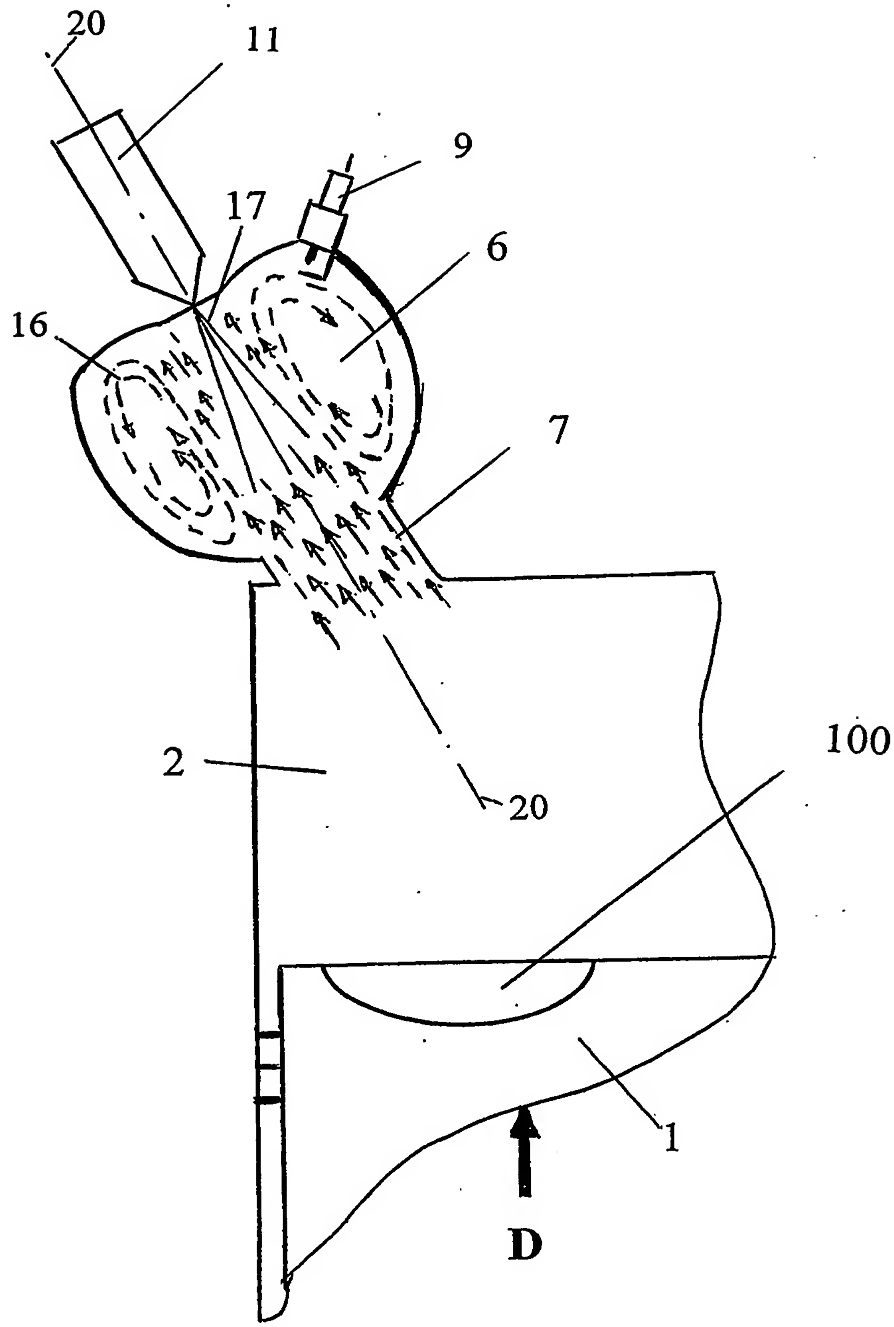

FIG. 6